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Velocity Estimation of the Main Portal Vein with Transverse Oscillation

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Abstract— This study evaluates if Transverse Oscillation (TO) can provide reliable and accurate peak velocity estimates of blood flow the main portal vein. TO was evaluated against the recommended and most widely used technique for portal flow estimation, Spectral Doppler Ultrasound (SDU). The main portal vein delivers blood from the bowels to the liver, and patients with certain liver diseases have decreased flow in the portal vein. Errors in velocity estimation with SDU are well described, when the beam-to-flow angle is >70 degrees. TO estimates the flow angle independently and is not limited by the beam-to-flow angle. It is less operators depended, as no angle correction is necessary. TO measurements were performed with a 3 MHz convex probe (BK medical 8820e, Herlev, Denmark) connected to the experimental ultrasound scanner SARUS (Synthetic Aperture Real-time Ultrasound Scanner). SDU velocity measurements were performed with a commercial ultrasound scanner (BK 3000, BK Ultrasound, Herlev Denmark) and a convex probe (BK ultrasound 6C2, Herlev, Denmark). Ten healthy volunteers were scanned, and recordings of the portal flow during 3-5 heartbeats were conducted with an intercostal and subcostal view. Intercostal TO peak velocities were not significantly different from SDU peak velocities (TO=0.203m/s, SDU=0.202m/s, $p=0.94$). Subcostal and Intercostal obtained TO values were not significantly different (intercostal mean TO=0.203m/s, subcostal mean TO=0.180m/s, $p=0.26$). SDU values obtained intercostal and subcostal were significantly different (intercostal mean SDU=0.202m/s, subcostal mean SDU=0.320m/s, $p<0.001$). Standard deviation for TO beam-to-flow angle was 10.3° - 91.5° , indicating a large beam-to-flow angle variability in the portal vein. This can affect the peak velocity estimation, and is not addressed in SDU. The TO convex array implementation provides the first vector velocity measurements below 60mm (mean 89mm), and is a useful alternative for flow estimation in abdominal ultrasound. It may provide new information of abdominal fluid dynamics and yield both velocity and angle estimates for a more realistic flow characterization.

Keywords— *Transverse Oscillation, Spectral Doppler, Vector Velocity Estimation, Main Portal Vein, Ultrasound Velocity Estimation*

I. INTRODUCTION

The hepatic portal vein conducts blood from the gastrointestinal tract and spleen to the liver. Increased blood pressure in the portal vein is denoted portal hypertension and is a major complication in liver diseases, most commonly liver cirrhosis. Complications to portal hypertension (e.g. ascites, esophageal and gastric varices, and splenomegaly) are often

fatal [1]. Portal vein hypertension can lead to a reduced velocity and in advanced stages the portal vein flow becomes reversed [2, 3]. Ultrasound is usually the first diagnostic modality for assessment of portal flow, since it is easily accessible, radiation free, and cheap. The European Federation of Societies for Ultrasound in Medicine and Biology recommends evaluation of peak velocity in the main portal vein in patients suspected for portal hypertension using Spectral Doppler Ultrasound (SDU) [4].

Errors in velocity measurement with SDU are well described, when the beam-to-flow angle is >70 degrees to the main portal vein [5]. Furthermore, operator dependency has shown to be a major bias in Doppler ultrasound [6]. Other factors as body position, phase of respiration, timing of meals, exercise and cardiac output can affect the accuracy of velocity measurements, and change the flow profile of the liver vasculature. However, Doppler ultrasound is accepted as a useful technique for evaluating patients with cirrhosis and portal hypertension [7].

Transverse Oscillation (TO) measures the vector velocity independently of the beam-to-flow angle. Both the axial and the transverse velocity are found and used to calculate the vector velocity. The axial velocity is found using conventional velocity estimation, while the transverse velocity is found by manipulating the receive beamforming. TO is described thoroughly by Jensen, Munk and Udesen [8, 9, 10]. Vector velocity is a novel technique, and recent studies have indicated that TO is ready for clinical scanning [11-15]. Clinical TO examinations have until now been limited by the implementation, as TO only worked on a linear array transducer with a scan depth of approximately 60mm. For abdominal scanning an increased scan depth is needed. TO was implemented on a convex array transducer for this purpose [16].

The preferred scan position for evaluation flow in the main portal vein is an intercostal view (between the ribs on the right side of the thorax) (Fig. 1). The beam-to-flow angle is in this position around 0 degree, as the vessel flow is going straight towards the transducer, and SDU velocity estimation in this position is reliable [4]. With a subcostal view (under the ribs curvature) (Fig. 1), the main portal vein can be visualized, but the beam-to-flow angle is in this position about 90 degrees, thus, impossible to measure with SDU. TO may provide reliable velocity estimation with this view. The hypothesis of this study is therefore, firstly to determine if TO on a convex

array can provide reliable peak velocity estimates in the main portal vein with an intercostal view compared to SDU, and secondly, to determine if TO can provide an accurate flow estimate of the portal vein with a subcostal view.

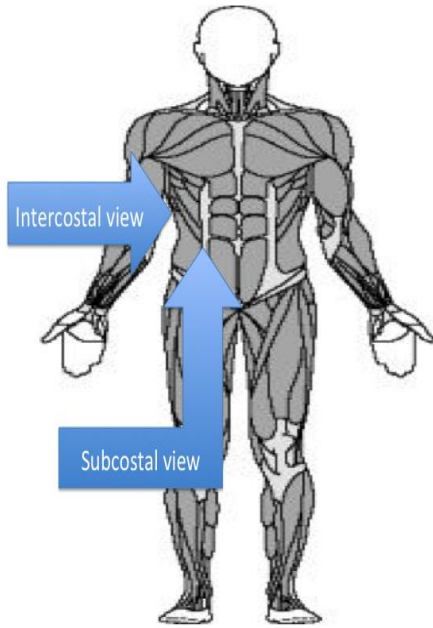


Figure 1: Schematic illustration of the intercostal and subcostal scan position.

II. MATERIALS AND METHODS

A. Equipment and data acquisition

TO velocity measurements were performed with a 3 MHz convex probe (BK medical 8820e, Herlev, Denmark) connected to the experimental ultrasound scanner SARUS (Synthetic Aperture Real-time Ultrasound Scanner). SDU velocity measurements were performed with a commercial ultrasound scanner (BK 3000, BK Ultrasound, Herlev Denmark) and a convex probe (BK Ultrasound 6C2, Herlev, Denmark). An in-house developed algorithm in MATLAB (MathWorks, Natick, MA, USA) was used for peak velocity estimation with TO and is previously described thoroughly by Jensen et al. [16]. Beam-to-flow angle for TO was calculated by the vector diversity and averaged along the centerline of the vessel. Standard deviation for the beam-to-flow angle specified vector diversity for the mean beam-to-flow angle of TO. SDU peak velocities and fixed beam-to-flow angle information was gathered with the standard spectral Doppler setup on the commercial scanner.

B. Patients and Scan Setup

Ten male healthy volunteers (mean age: 28.8; range: 26-32) were included in the study. Health status of each volunteer was obtained by interview. All were included after informed consent and after obtained approval by the Danish National Committee on Biomedical Research Ethics (H-1-2014-FSP-072). All volunteers were scanned in supine position by a single medical doctor (A.H.B.). The volunteers were asked to

hold their breath in a mid or full respiratory level, while measurements were performed. Blood pressure and heart rate were assessed before the scan. With both methods, the portal flow was estimated in a intercostal and subcostal scan position, corresponding to 4 measurements for each volunteer. The commercial scanner was used for guidance before scanning with the SARUS, as the preview image for SARUS had limited frame rate and image quality. Each participant was scanned with both techniques within 30 min.

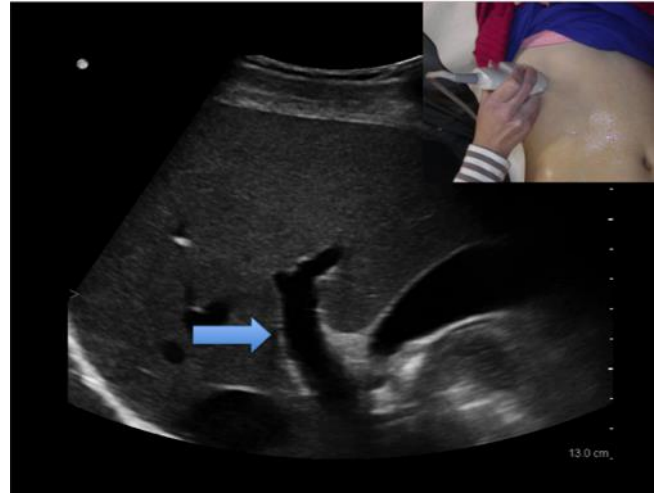


Figure 2: Intercostal view of the main portal vein (blue arrow) scanned with the commercial scanner.

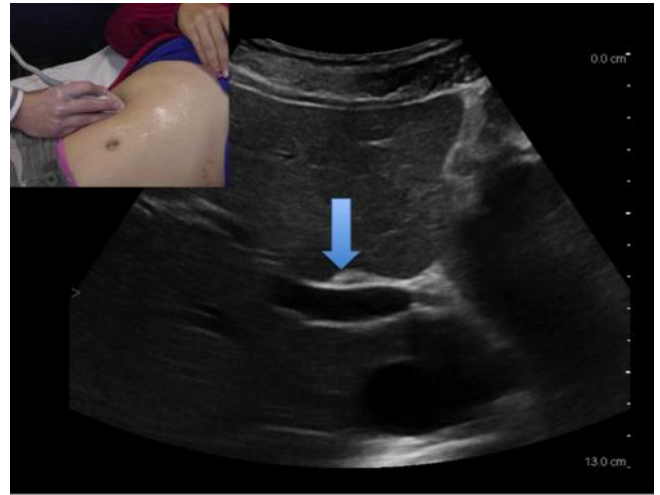


Figure 3: Subcostal view of the main portal vein (blue arrow) scanned with the commercial scanner.

C. Statistics

For descriptive analyses, the mean peak velocity and standard deviation were calculated for subcostal and intercostal scan position with TO and SDU. Differences between SDU and TO was analyzed with a paired t-test for both views. As the peak velocities values of the subcostal and intercostal view should be the same regardless of the method employed, the values were used as their own reference and

differences for each method was analyzed with a paired t-test. Statistical significance level was set at 0.05. Mean beam-to-flow angle for TO was calculated and given in mean for intercostal and subcostal view with standard deviation presenting vector diversity. Data were handled in with MATLAB (MathWorks, Natick, MA, USA) and Microsoft Excel (Redmond, WA, USA).

III. RESULTS

All participants had a normal heart rate (mean: 61 beats/min (range: 47-87) and blood pressure (mean systolic pressure 127 (range: 108-140); mean diastolic pressure 76 (range: 74-85)). BMI values were (mean BMI 23.9; range: 20.9-27.2).

Peak velocities from all volunteers for TO and SDU are shown in Figure 4. Intercostal obtained TO peak velocities were not significantly different from intercostal obtained SDU peak velocities (mean TO=0.203 m/s, mean SDU=0.202 m/s, $p=0.94$). Subcostal obtained TO values were significantly different from subcostal obtained SDU values (mean TO=0.180m/s, mean SDU=0.320m/s, $p<0.001$). TO peak velocity obtained with an intercostal view were not significantly different from TO obtained values with a subcostal view (intercostal mean TO=0.203m/s, subcostal mean TO=0.180m/s, $p=0.26$). Intercostal obtained SDU values were significantly different from subcostal obtained values (intercostal mean SDU=0.202m/s, subcostal mean SDU=0.320m/s, $p<0.001$).

Range for the TO mean beam-to-flow angle was 9° - 61° with the intercostal view and 4° - 39° with SDU. The mean TO subcostal view beam-to-flow angle range was 53° - 130° and 57° - 99° with SDU. Standard deviation for TO mean beam-to-flow angle was between 7.8° - 91.5° . Mean scan depth for TO was 89 mm with a range of 59-104 mm. An example from a volunteer scanned in intercostal view with SDU and TO is shown in Figs. 5 and 6.

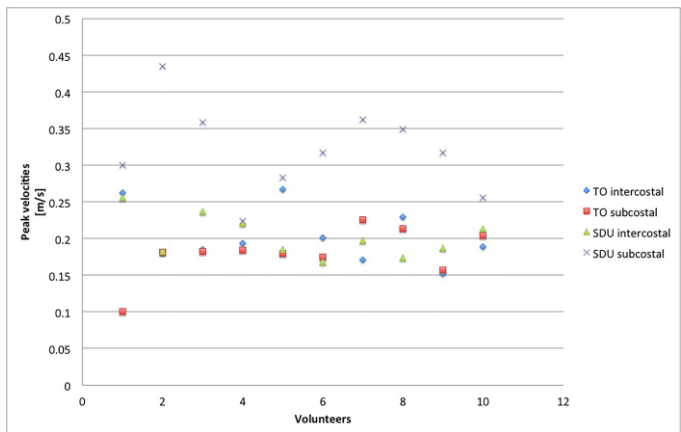


Figure 4: Peak velocities for each volunteer and each view obtained with both techniques.

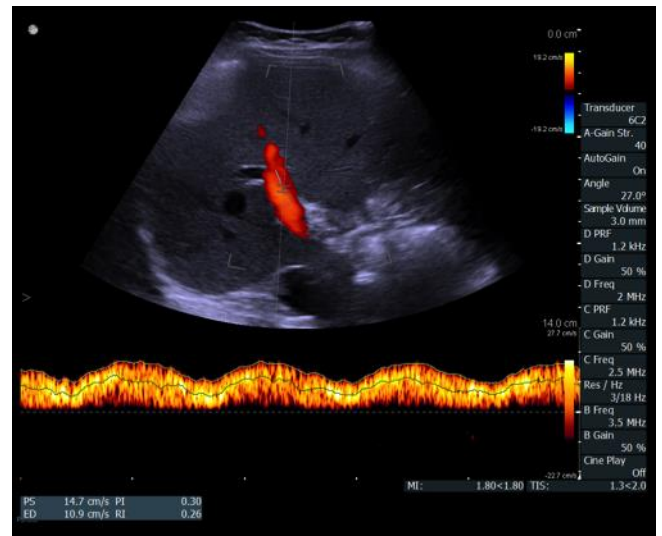


Figure 5: Example from volunteer scanned with the commercial scanner with a intercostal view.

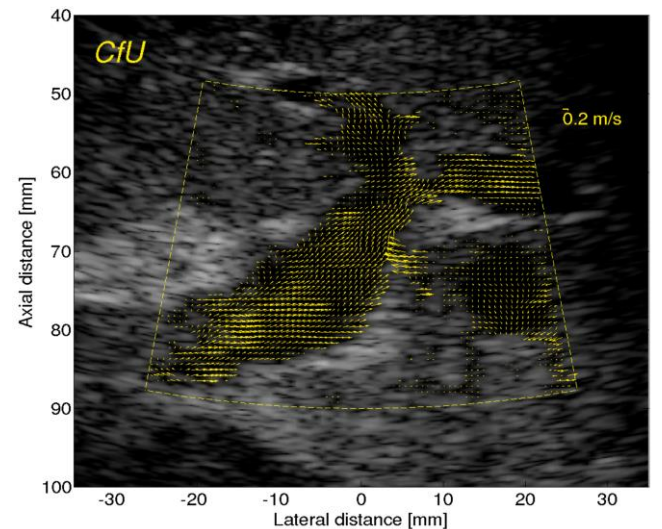


Figure 6: Example from volunteer with the TO setup from a intercostal view.

IV. DISCUSSION

This is the first study to examine peak velocity obtained by TO in the main portal compared to SDU. SDU is only reported to measure correct peak velocities with an intercostal view [4], and overestimates the flow with a subcostal view. With the accepted view for SDU (intercostal), TO peak velocities were not significantly different from SDU peak velocities, while values were as expected significantly different with the subcostal view. Measurement performed with a subcostal and intercostal view for TO were not significantly different, while values were significantly different for SDU. This clearly shows TO angle independence, and that TO can offer a reliable evaluation of the peak velocity in the portal vein with views, which are not achievable with SDU. For clinical evaluation of patients treated with liver surgery or liver transplantation, this could be an advantage since the liver

anatomy and portal vein position is altered, and hereby hampering the evaluation with SDU [4].

Performing SDU measurement requires training. Adjusting the Doppler angle, position the sample volume, adjusting of the spectral gain, and adjustment of the display scale are all known sources of error [5, 17]. Experienced ultrasound users are known to estimate errors up to 28% in peak velocity values on vessel phantoms [6]. The solution to SDU errors could be TO, as angle independent vector velocity estimation with TO is less operator dependent than SDU [12, 18].

Standard deviation for the beam-to-flow angle of TO has previously been reported to be around 3° in a simulation phantom study [8], but the measured standard deviation in this study was 10.3°- 91.5°. There is, thus, large vector diversity, when measuring flow in the portal vein, indicating that the flow is not laminar. This greatly affects the peak velocity estimate and cannot be detected with SDU, since SDU assumes a fixed beam-to-flow angle. TO may therefore provide new information of abdominal fluid dynamics and yield both velocity and angle estimates for a more realistic flow characterization.

Furthermore, this is the first TO convex array implementation providing vector velocity measurements below 60 mm. This shows that TO is a useful angle independent alternative for flow estimation in medical abdominal ultrasound.

Future studies where the reproducibility of TO compared to SDU in a larger study population are under preparation. A TO implementation on a commercial scanner is considered for a larger study with patients suffering from liver disease.

V. CONCLUSION

This study indicates that TO is a useful alternative for velocity estimation in the main portal vein. TO estimated the same peak velocities as SDU in healthy volunteers. Furthermore, TO estimates identical values with a subcostal view, which is inapplicable for SDU, thus, a new insonation window of the portal flow is introduced with TO. TO can provide new information to abdominal fluid dynamics. This could improve the clinical examination of patients suffering from liver disease.

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